Energy Research and Development Division
FINAL PROJECT REPORT

Laboratory Testing and Field Measurement of Plug-in Electric Vehicle (PEV) Grid Impacts

Appendix G

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APPENDIX G:
Distribution Circuit Survey

Distribution Circuit Survey

Task 2.2 Report: SDG&E Distribution Circuit Selection for Test Bed Design and Electric Vehicle Impact Tests: Distribution System Survey, Prioritization for Testing, and Test Bed Design

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1. Introduction

Task 2 of the Plug-In Electric Vehicle (PEV) simulator project *Field Measurement of PEV Grid Impacts* is to design and conduct testing on the distribution grid to determine the effect and impact of PEV charging. Task 2.2 aims to survey the existing SDG&E distribution systems and conduct studies to locate circuits or areas where significant PEV charging impact is most likely to occur so that a test bed can be designed to replicate and analyze the impacted system. For this purpose, the data collection focus is on the circuits that currently include most PEV installations.

SDG&E has provided basic circuit characteristics for the top 11 circuits that have the most number of PEV customers at present. The included circuit features are:

- Voltage level
- Associated substation
- Circuit capacity in Amps
- Service transformer count and their total rated capacity per circuit
- Customer count and composition (residential, commercial and industrial customers) per circuit
- Circuit length (overhead vs. underground)
- 2012 circuit peak load
- Number of PEV installations per circuit
- Type of voltage control devices on a circuit (e.g., fixed/switched shunt capacitors and voltage regulators)

In addition, detailed information on 1276 PEV installations was provided as a supplementary database. The information provided in this database includes:

- PEV installation location (city, geographical coordinates and circuit)
- PEV information (make, model and year)
- Battery information (type, capacity, charging voltage and maximum charging rate)
- Electric Vehicle Supply Equipment (EVSE) information (type, voltage and maximum amp rating)

The map in Figure 1 shows the concentration of the PEV installations in the SDG&E system territory. The locations are identified by four categories of single- or multiple-PEV customers per transformer and areas with combined PV generation and PEV load on the same transformer.

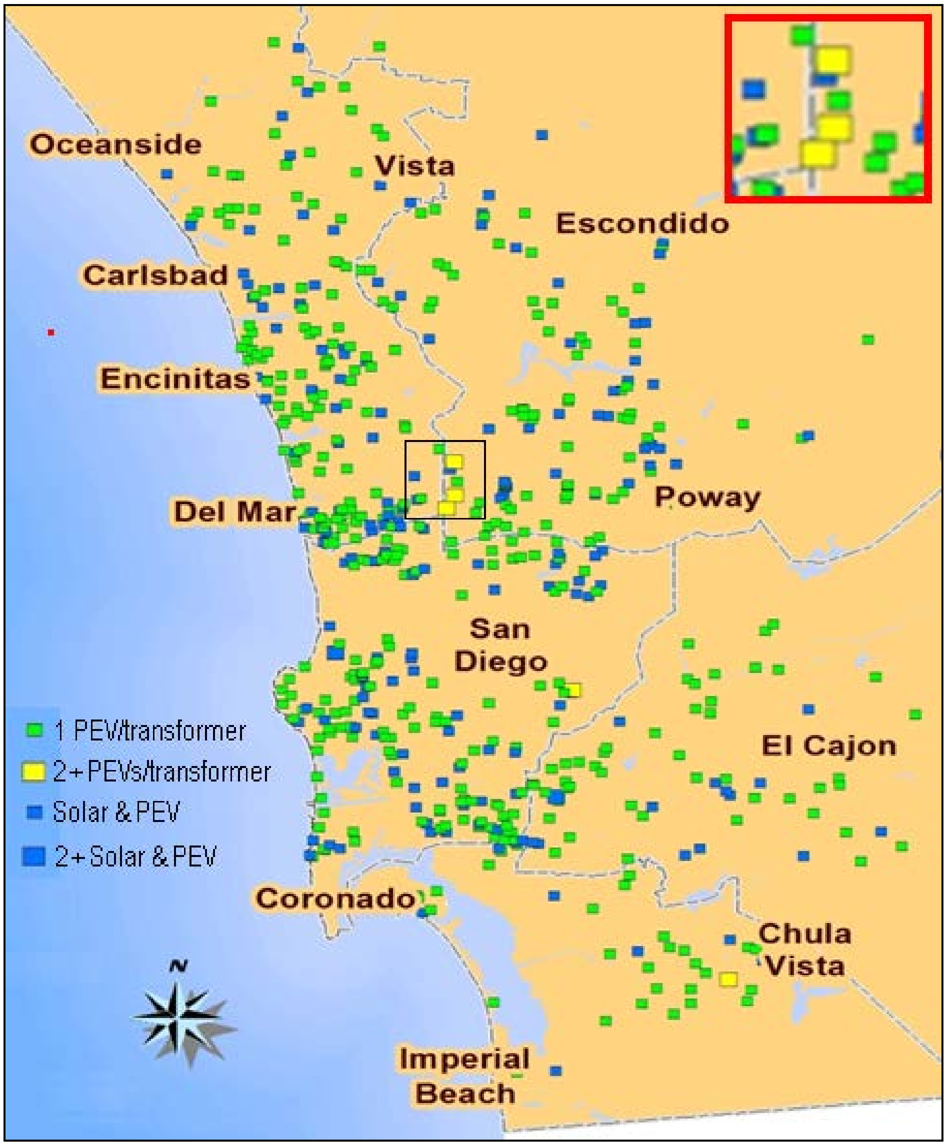

Figure 1 - PEC customer concentration in SDG&E system territory - Oct 2012

2. Representative Circuit Selection

2.1 *Circuit Selection Approach*

In order to provide a basis for the design of a test bed replicating impacted areas, a representative circuit shall be selected by considering, not only its likelihood of being impacted by high penetration of PEV charging, but also its representativeness in terms of existing PEV installations. For example, if a circuit in the PEV early adopting region has significantly more PEVs already installed than its neighboring circuits, this circuit is not as representative as one that has similar PEV installations as its neighboring circuits. Ideally, detailed data such as customer income level and their willingness to advocate environment protection would be used to analyze the PEV adoption likelihood. However, due to the limitation in obtaining this sort of information, the survey study was performed by extracting underlying implicative information from available data and utilizing the information to select representative circuits.

The features used in the survey are outlined below:

- PEV regional adoption rate: the percent of PEVs from the substation feeding the studied circuit (out of total 1276 PEVs). The more PEVs the feeding substation supports, the more likely the customers in that area are to adopt PEVs, especially at the early stages.
- PEV adoption diversity factor: the reciprocal of the percent of PEVs on the circuit over the total number of PEVs the feeding substation supports. The larger the factor is, the smaller PEV percentage the circuit has in the same substation. In other words, the smaller the PEV concentration on the circuit is, the more representative this circuit is in terms of its PEV adopting pace.
- Circuit length: the longer the circuit is, the more concerns with regard to voltage violation it has when more PEV installations are in place, especially when locations of PEV installations are at a customer's premise, outside of utility control.
- PEV circuit adoption rate: the percentage of residential customers owning PEVs. Currently, all PEV customers own only one PEV. The number of PEVs represents the number of customers owning a PEV.

- <u>PEV load factor</u>: the percentage of PEV charge load related to the 2012 circuit peak load. Its magnitude is represented by the product of the number of PEVs on the circuit and the power draw of a Nissan Leaf. This is a reasonable assumption as:
    - The Nissan LEAF dominates SDG&E's service territory in most early adopting circuits.
    - The maximum PEV charging rate is 3.3kW for Chevy VOLT and 3.7kW for Nissan LEAF. The difference is not significant.
    - In many cases, the exact model is unknown.

These five extracted attributes cover the likelihood of PEV adoption, both at the regional level and circuit level. They include the potential impact of PEVs on circuit loading and voltage profile, and also take into consideration the circuit representativeness among all possible circuits in the SDG&E territory.

Based on the current data availability, it is not statistically significant to quantify a threshold to determine different levels of PEV adoption likelihood. Therefore, a fuzzy inference system was developed to rank the likelihood of high-PEV adoption for the top 11 circuits.

A brief introduction of fuzzy inference system is presented as follows. Detailed tutorials about fuzzy logic and fuzzy inference systems can be found online or in any fuzzy logic reference book. Fuzzy logic allows for approximate values and inferences, as well as incomplete or ambiguous data (fuzzy data), as opposed to only relying on crisp data [1]. A membership function is the tool to define how each input is mapped to the degree of membership of each fuzzy category. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping provides a basis from which decisions can be made or patterns discerned [2].

For the purpose of this analysis, the input data are first normalized to the range of [0, 1] to avoid any potential bias due to different input variable magnitude. Then, a commonly used triangle membership function is applied for both input and output variables. Basic "if-then" rules are used to define the mapping from circuit features to the likelihood of a circuit being impacted by high penetration of PEV charging. The analysis then aggregates the output from different rules, and uses the most popular centroid method to de-fuzzify the aggregated fuzzy set into a single number, which is used as the final score of the circuit's likelihood of being exposed to high-PEV penetration impact. A more detailed explanation and an example of the calculation, is presented in Appendix A.

2.2 *Circuit Ranking and Recommendations*

The final score and ranking of the top 11 candidate circuits to be selected for system replication are listed in Table 1, along with the values for the five extracted input attributes. The detailed methodology and raw data for these five input attributes are presented in Appendix A and B respectively for review.

Table 1 - Circuit ranking and values for attributes

Circuit ID	# PEV	Regional Adoption Rate	Circuit Adoption Rate	Adoption Diversity Factor	Circuit Length	Load Factor	Score	Rank
A	14	4.94%	0.81%	4.50	19,953	7.41%	**0.572**	1
B	23	5.17%	1.05%	2.87	46,848	4.36%	**0.565**	2
C	17	5.17%	0.74%	3.88	30,203	4.21%	**0.526**	3
D	12	4.94%	0.35%	5.25	37,472	2.53%	**0.504**	4
E	11	3.92%	0.40%	4.55	42,646	2.70%	**0.501**	5
F	11	3.92%	0.42%	4.55	27,682	4.95%	**0.499**	6
G	11	3.92%	0.24%	4.55	41,352	2.32%	**0.489**	7
H	15	2.59%	0.74%	2.20	34,032	3.21%	**0.453**	8
I	11	1.10%	0.35%	1.27	54,086	2.93%	**0.408**	9
J	11	1.10%	0.30%	1.27	36,690	2.85%	**0.377**	10
K	11	1.65%	0.33%	1.91	27,458	2.47%	**0.371**	11

This ranking is derived based on the aggregated consideration of five different features. Even though the number of existing PEVs (#PEV) is not directly used as an input for the fuzzy inference algorithm, the final ranking of the top 11 circuits is generally consistent with their number of PEVs in the system. One exception is that circuit A with 14 PEVs is ranked as No.1, but circuit H with 15 PEVs is ranked much lower.

Three of the five attributes (Regional Adoption Rate, Adoption Diversity Factor and Circuit Length) are not directly associated with the number of PEVs on a given circuit. Although the two remaining attributes (Circuit Adoption Rate and Load Factor) are derived from the number of existing PEVs on the circuit, they are normalized by different features. Therefore, it is reasonable to claim that the ranking is not biased by one single factor, namely the number of PEVs, even though the derived circuit ranking is consistent.

The top two circuits will be selected for further analysis in order to extract circuit characteristics and to understand PEV charging patterns. The top four ranked circuits are fed by two substations. Circuits B and C are associated with a common substation, while circuits A and D are from another common substation. If more circuits are to be selected for study, it is recommended to select circuits from different substations to ensure their representativeness.

It is worth noting that all 11 candidate circuits are among the ones with the highest PEV penetration at the moment. They do not represent circuits with no PEV customers or with few PEV installations. Therefore, the selected circuit is only representative of small group of circuits with PEV customers and do not generally represent the characteristics of the entire system. However, the score of each circuit listed in Table 1 would provide a good view of the likelihood of high- PEV impact based on current adoption rates. This same methodology can be applied to all the circuits in the SDG&E system to calculate their corresponding scores if needed.

2.3 Short-, Medium- and Long-term Impacts

PEV charging can impose significant direct and indirect, short-term and long-term impacts on distribution systems. Typical direct impacts of PEV charging include overloaded distribution transformers, overloaded conductor and cable, low voltage to customers, and potential violation of utility planning limits [3]. Due to the vehicle clustering effect seen in early adoption stages, some local areas may experience significant impact, even at low-PEV penetration. If PEV charging is uncontrolled, customers might charge their vehicles upon their arrival at home, generally the same time of day when feeders have heavy loads, if not at their peaks. As a result, the distribution system will face severe impacts on capacity and reliability due to undesirable peaks. PEV charging control approaches, such as time-of-use (TOU) rates and smart charging, can help mitigate or eliminate some of these impacts. Additional infrastructure, metering, monitoring and control equipment is required for controlled PEV charging. Utilities need to pay attention to the possible formation of new system peak, especially at higher PEV penetration. Even though charging control may be able to mitigate the equipment overload issue, when equipment is operating at higher loading conditions for a longer period, its life expectancy will be reduced.

PEV charging impacts are primarily determined by the location of PEVs on the distribution circuit, the time of day PEVs are charging, the power draw magnitude of PEV charging, and the duration of the charge cycle. Detailed metering data from current PEV customers in the SDG&E service territory were gathered to extract the typical PEV charging patterns, which are presented in the following section and will be included in the test bed design. The targeted test bed design, based on the representative circuit chosen, is intended to evaluate the impacts of PEV charging on distribution system thermal loading, voltage regulation, transformer loss of life, voltage imbalance and harmonic distortion levels. The top two ranked circuits mentioned in the circuit selection section will be further reviewed for characteristic selection and development of the test bed design. The test bed will attempt to replicate common characteristics of the impacted areas identified on these top ranked circuits. In order to determine both circuit level impacts and individual component level impacts, the analysis will incorporate scaling of the number of PEV customers per service transformer at various locations and the extracted charging profiles.

3. PEV Customer Behavioral Charging Patterns

The PEV customer metering data from the five circuits with the most PEVs were analyzed for PEV charging patterns. Of the data available for 46 customers, 29 have PEV metering data exclusively. These exclusive PEV metering points are used for customer PEV charging pattern extraction. Most of the customer metering data, collected at 15-minute intervals, contain slightly more than one year of historical load information.

SDG&E has three experimental service schedules for residential customers, exclusively for charging a PEV. The detailed information for these service schedules is presented in Table 2.

- EVEL-H service: 9 out of 29 customers enrolled
- EVEL-M service: 13 out of 29 customers enrolled
- EVEL-L service: 7 out of 29 customers enrolled

Table 2 – Experimental Service Schedule

Season	Schedule	Time Period	Rate ($/kWh)		
			EVEL-H	EVEL-M	EVEL-L
Summer	On-Peak	12PM-8PM	0.38342	0.29248	0.26753
	Super Off-Peak	12AM-5AM	0.06715	0.07636	0.13340
	Off-Peak	8PM-12AM 5AM-12PM	0.15337	0.18395	0.16313
Winter	On-Peak	12PM-8PM	0.33465	0.24501	0.17240
	Super Off-Peak	12AM-5AM	0.06928	0.08086	0.13903
	Off-Peak	8PM-12AM 5AM-12PM	0.13386	0.16334	0.16577

3.1 *Charging Time*

Figure 2 shows the distribution of time when customers charge their PEVs on a given day. Each color represents one of the 29 customers. The majority of the PEV charging events start at midnight when the super off-peak rate is effective. As time approaches morning, more and more PEVs finish their charging and a clear decreasing trend in PEV charging events is shown. Most of the charging events are completed before 5AM when the super-off peak period ends. During the daytime, some PEV charging events occur, but at a much smaller frequency, which is mainly due to occasional charging needs.

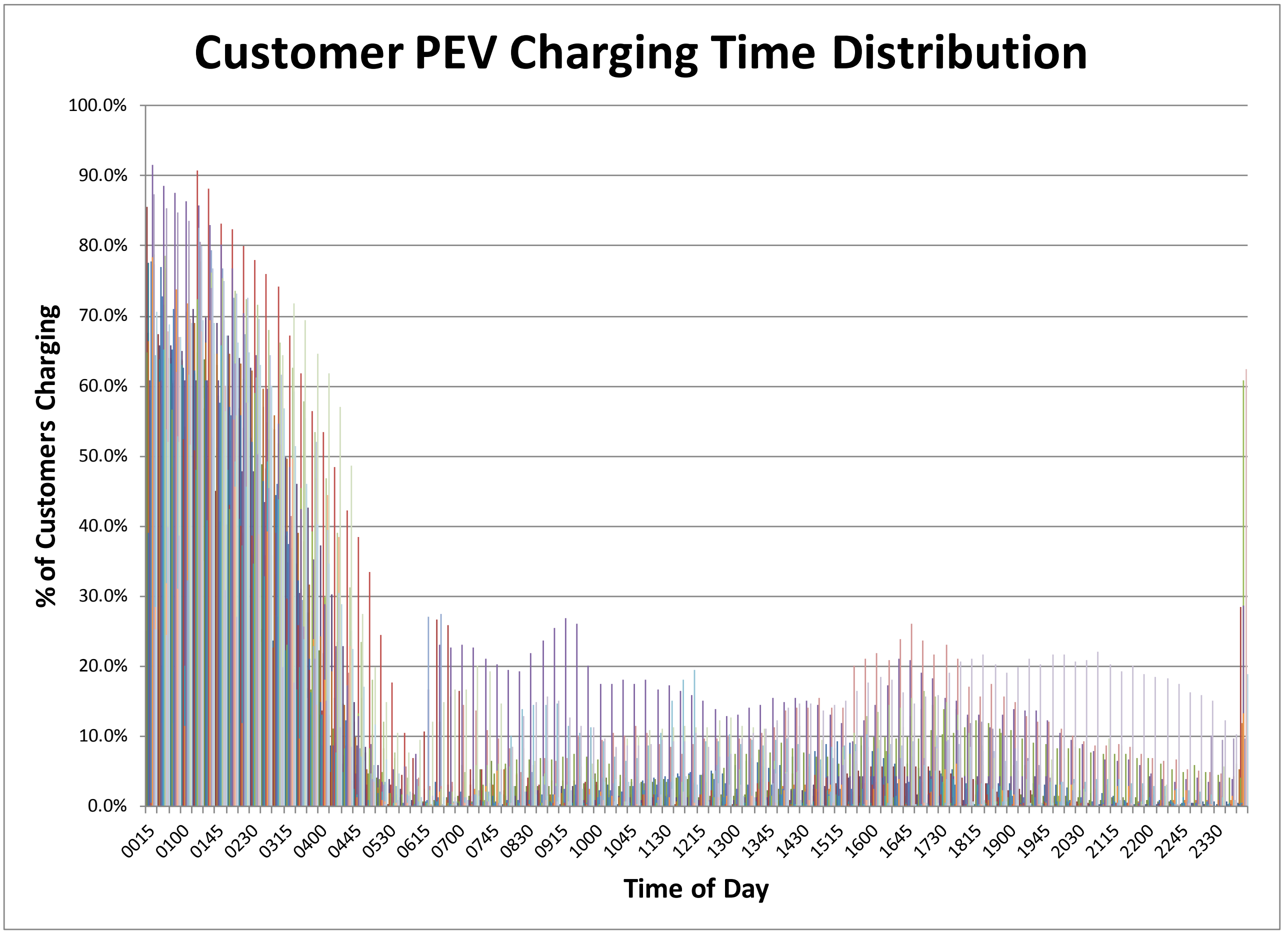

Figure 2 – PEV Charging Time Distribution (29 Customers)

Figure 3 shows the percent of customers charging at given times, which represents the average profile of PEV charging time of all 29 customers. It can be seen that:

- At midnight, more than half of PEV customers start charging their vehicles. The majority of the charging is completed before 5AM.
- Less than 10% of customers charge their PEVs during the rest of the day or the non "super-off-peak" rate period.

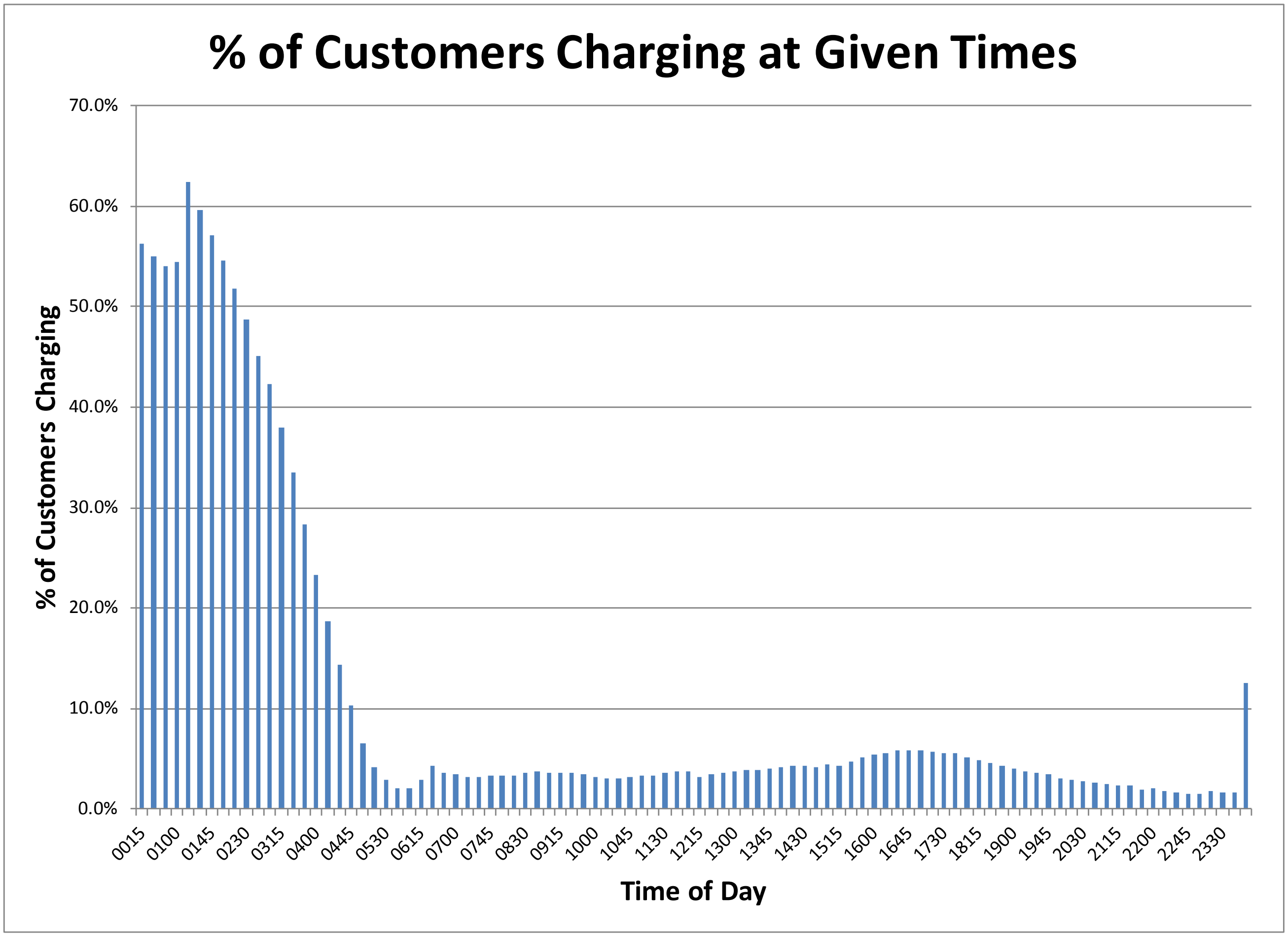

Figure 3 – % of Customers Charging at Given Times (29 Customers)

In order to examine the impact of different rate schedules to PEV customer charging times, the customers from different rate schedules are grouped together. The average charging time patterns of three rate schedule groups are presented in Figure 4. The distributions of PEV charging time for different rate schedule groups are presented in Appendix C. Some differences have been observed between 12AM and 1AM for three rate schedule groups. The inconsistency between the charging patterns dissipates after 1:15AM into a consistent pattern for customers of all three rate schedule groups.

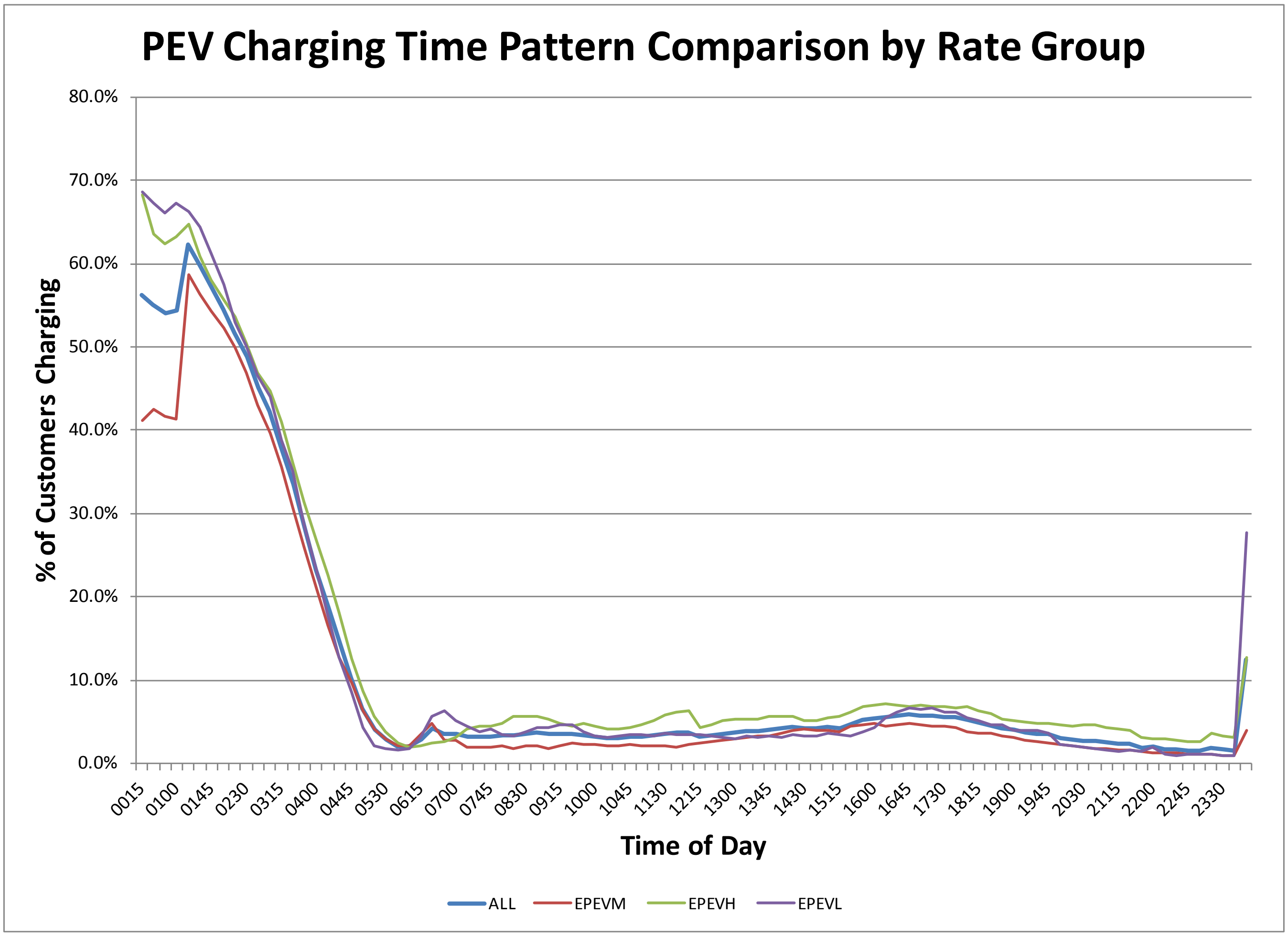

Figure 4 – Comparison of PEV Charging Time Pattern by Rate Group

As all experimental rate schedules have different rates for summer and winter, the PEV customer charging time pattern is also examined by season to understand its impact. Figure 5 shows the average charging time patterns in different season groups. It is clear that the patterns of PEV charging time in winter and summer are consistent.

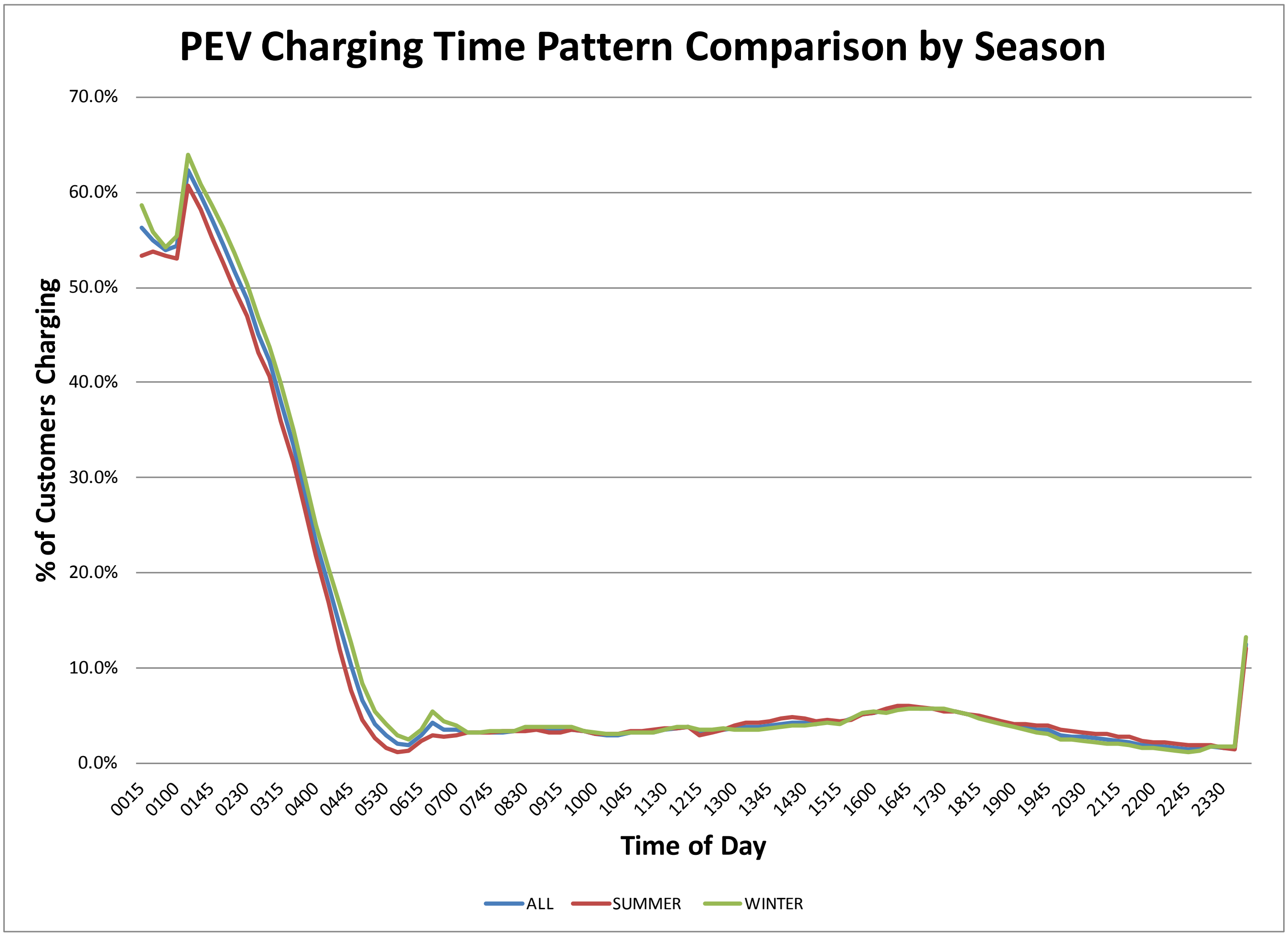

Figure 5 – Comparison of PEV Charging Time Pattern by Season

As a result, it is reasonable to use the average profile of PEV charging time (shown in Figure 3) to represent a typical pattern of when PEVs are charging. The numeric average PEV charging time pattern is presented in Appendix C. In addition to charging time patterns, PEV charging demand patterns are required to accurately simulate the impact of PEV charging to the system.

3.2 *Charging Demand*

PEV charging demand is another important factor in determining PEV charging impact to the distribution systems. Figure 6 represents the distribution of 15-minute energy consumption due to PEV charging. Each color represents one of the 29 customers. As indicated in the distribution plot, when customers charge their PEVs, the energy consumption (at 15-minute intervals) for each charging event is typically at a constant level, except in the early morning. It can be roughly inferred that the typical charging demand is also at a constant level for most charging events. The smaller energy consumption of PEV charging in the early morning can be due to the ramp-down period of battery charging. It is noticed that one customer consumes significantly more energy than other customers between 10PM and 12AM, as shown in the right end of the distribution diagram, which might be due to fast charging.

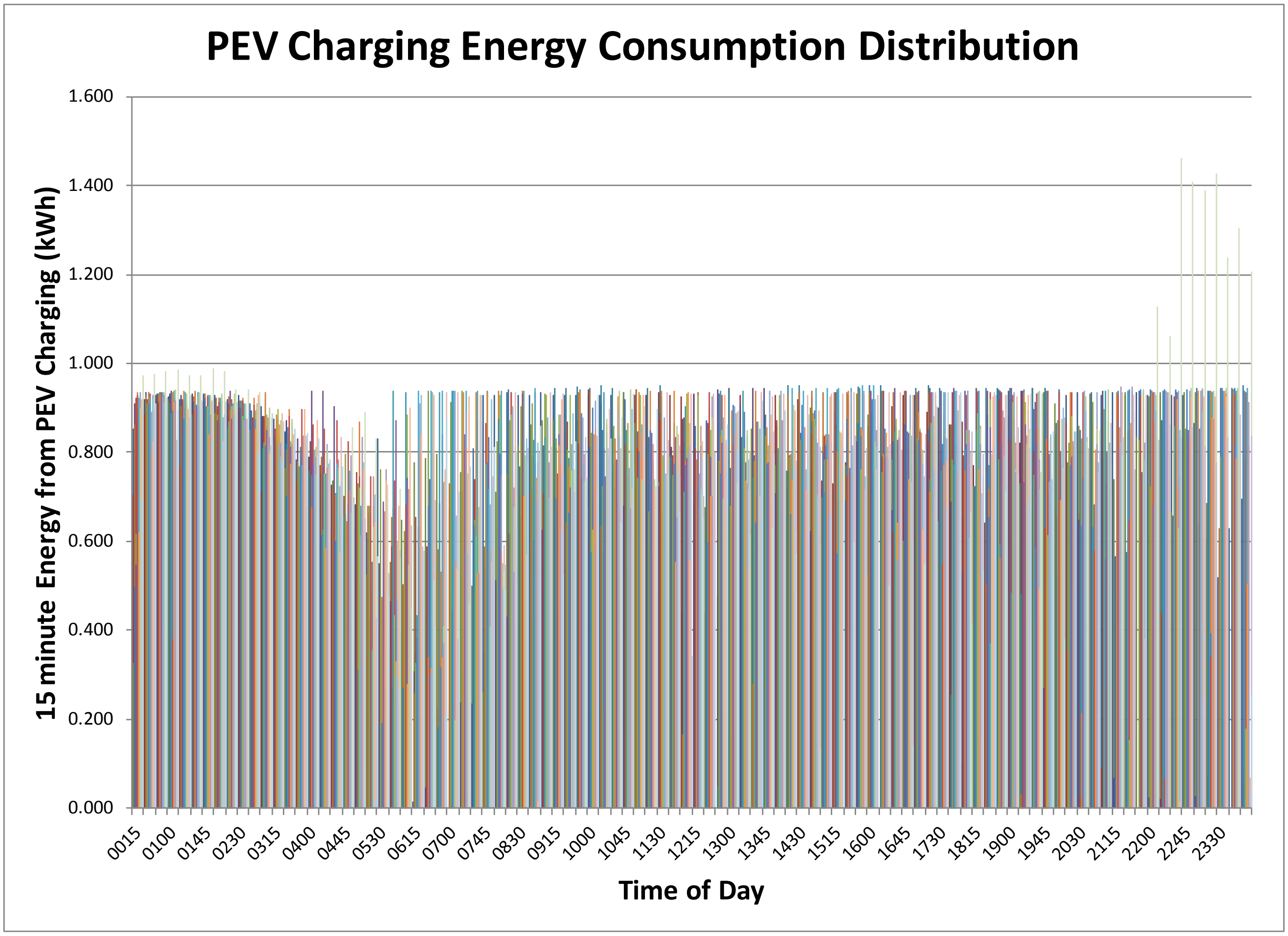

Figure 6 – PEV Charging 15-minute Energy Distribution (29 Customers)

Similar to the analysis for charging time patterns, the customers from different rate schedules and different seasons are grouped together, and their corresponding average charging demand patterns (converted from 15-minute energy consumption data) are presented in Figure 7 and Figure 8, respectively. It can be seen that the average charging demands in different groups (either by rate schedule or by season) have various degrees of fluctuation, but the overall pattern of the PEV charging demand over the course of a day is consistent for different rate groups. As a result, it is reasonable and sufficient to use the average profile of PEV charging demand, as shown in Figure 9. The numeric average PEV charging demand pattern is presented in Appendix C.

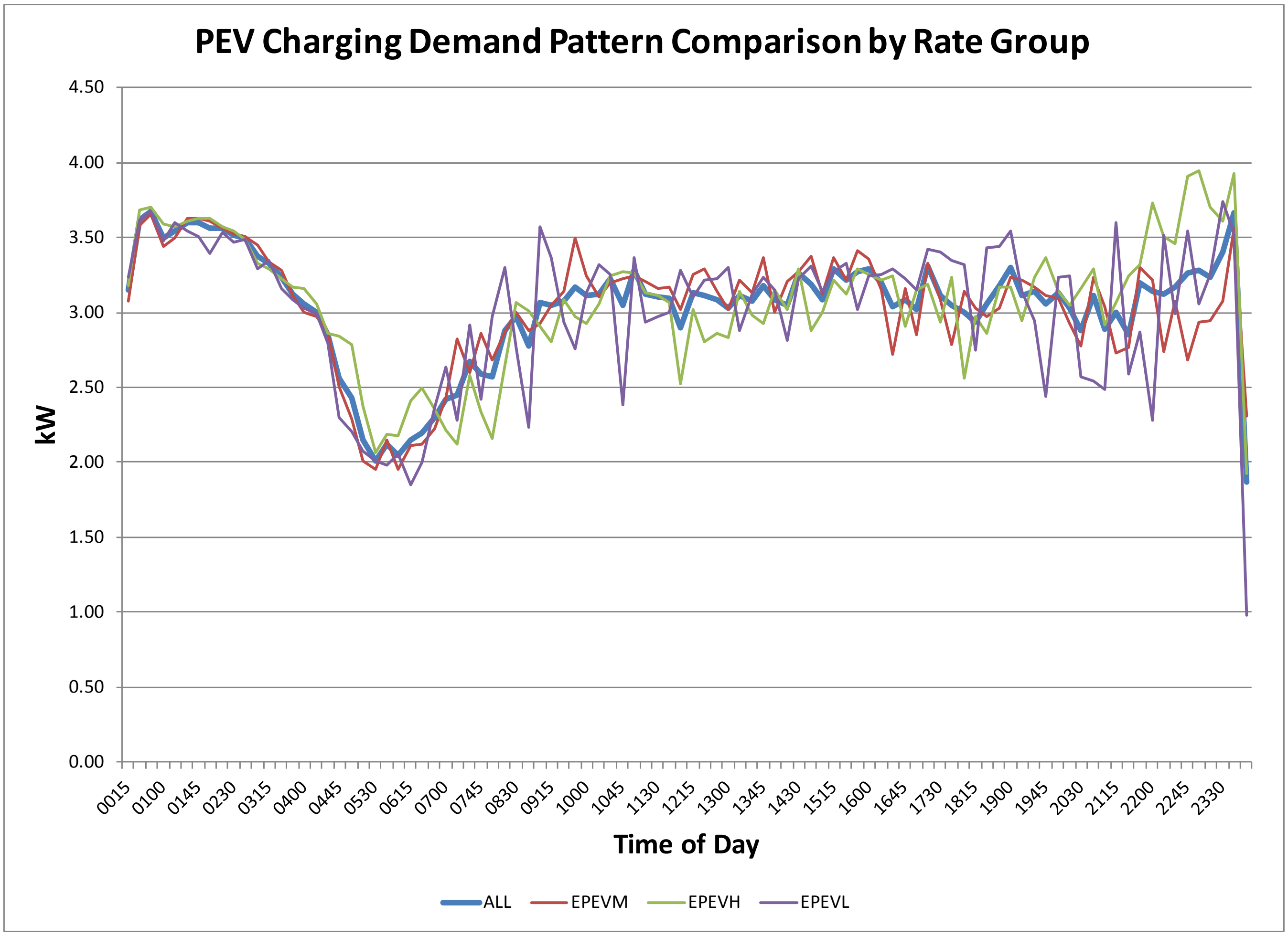

Figure 7 – Comparison of PEV Charging Demand Pattern by Rate Group

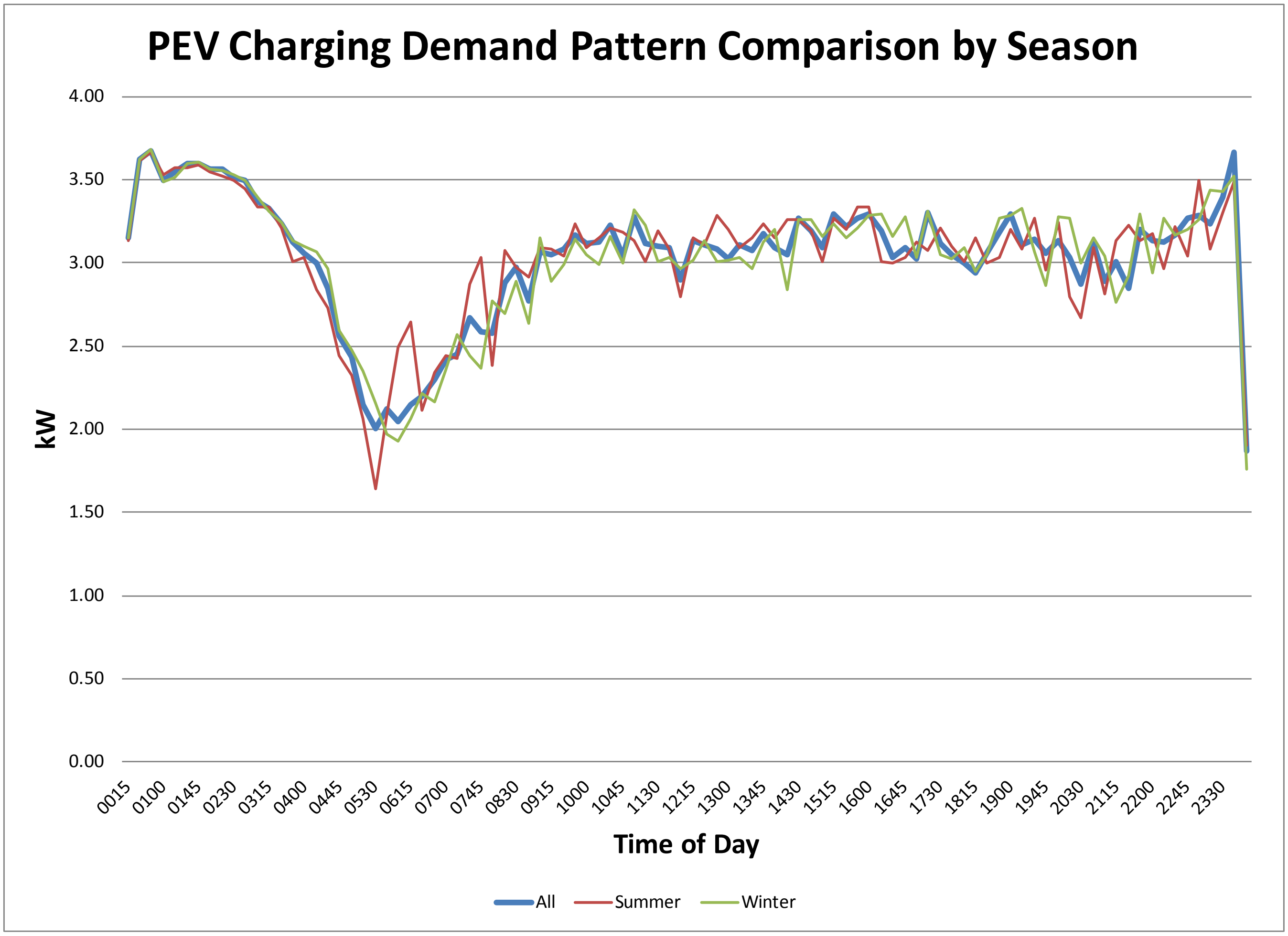

Figure 8 – Comparison of PEV Charging Demand Pattern by Season

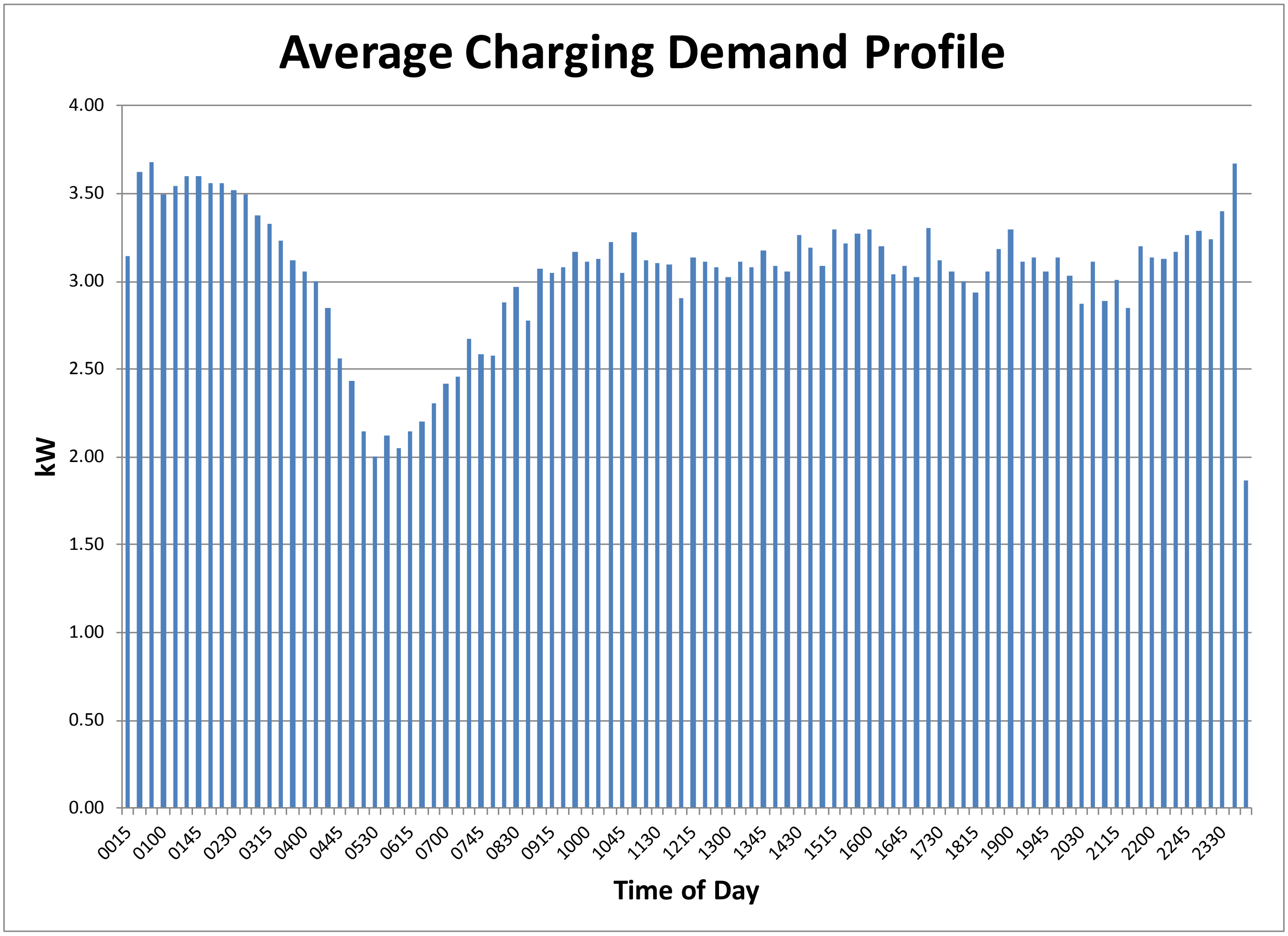

Figure 9 – Average PEV Charging Demand Distribution (29 Customers)

4. Summary and Conclusions

Task 2 of the Plug-In Electric Vehicle (PEV) simulator project *Field Measurement of PEV Grid Impacts* is to conduct testing on a representative distribution circuit in the SDG&E system territory to determine the real-world effect of PEV charging on the system. Task 2.2 particularly deals with surveying the SDG&E distribution systems that presently have PEV customers and performing studies to identify circuits or areas with high concentration of PEVs. The circuits with high penetration of customers will be the ones where significant adverse impact of PEV charging is most likely to occur. Hence, a test bed can be designed to replicate the circuit characteristics and analyze potential impacts.

In order to provide a basis for the test bed design, a representative circuit shall be selected by considering not only its likelihood of being impacted by high penetration of PEV customers, but also its representativeness in terms of similarities of circuit characteristics, as well as expected growth rate and number of existing PEV installations with those of other circuits.

SDG&E provided basic circuit characteristics for the top 11 circuits that have the most number of active PEV customers, as well as detailed information of 1276 PEV customers across their distribution territory. The survey study was performed by extracting underlying implicative information from available data and utilizing the information to prioritize and select top circuits.

A fuzzy inference system was developed to rank the likelihood of high-PEV adoption for the top 11 circuits. The top two ranked circuits were selected and reviewed for characteristic selection and development of the test bed design. The representative circuit will reflect the common characteristics of the impacted areas as identified for these top ranked circuits. The test bed will be the base for analyzing and evaluating the impact of the presence of PEV customers and various charging patterns on distribution system operation from several aspects, including:

- Exceeding equipment thermal loading
- Changes in the circuit voltage profile and potential for low voltage issues
- Increase in transformer loss of life and shortening of maintenance periods
- Possible voltage imbalance
- Affecting harmonic distortion levels

PEV charging impacts are primarily determined by the location of PEVs on the distribution circuit, number of PEV customers per service transformer, time of day when PEVs are charging, power consumption level of PEV charging (EV car type and charging level) and duration of the charge cycles. Detailed metering data from current PEV customers in the SDG&E service territory were gathered and analyzed to extract the typical PEV charging patterns in terms of time and demand.

The analyses showed that the majority of the PEV charging events started at midnight when the super off-peak rate was effective. As time approached morning, more and more PEVs had already completed their charging cycle. Most of the charging events were completed before 5AM when the super-off peak period ends. Less than 10% of customers charged their PEVs during the rest of the day or during the non "super-off-peak" rate period. It is also found that when customers charged their PEVs, the charging demand level was typically at a relatively constant level except during the ramp-down period of battery charging.

As of March 2013, there are about 3300 PEV customers in the SDG&E territory. A histogram of number of PEV customers by year and rate category is shown in Figure 10. About 60% of the PEV customers are on standard residential energy consumption rate, while the remaining 40% of the customers are registered under experimental PEV rate (EPEV) using individually metered PEV power consumption. Although EPEV rates have substantially driven customer to charge during off-peak and super-off-peak hours, there is no incentives for roughly 60% of EV customers to charge during off-peak hours. The customers to rate ratio will be considered in the testing and development of the test setup.

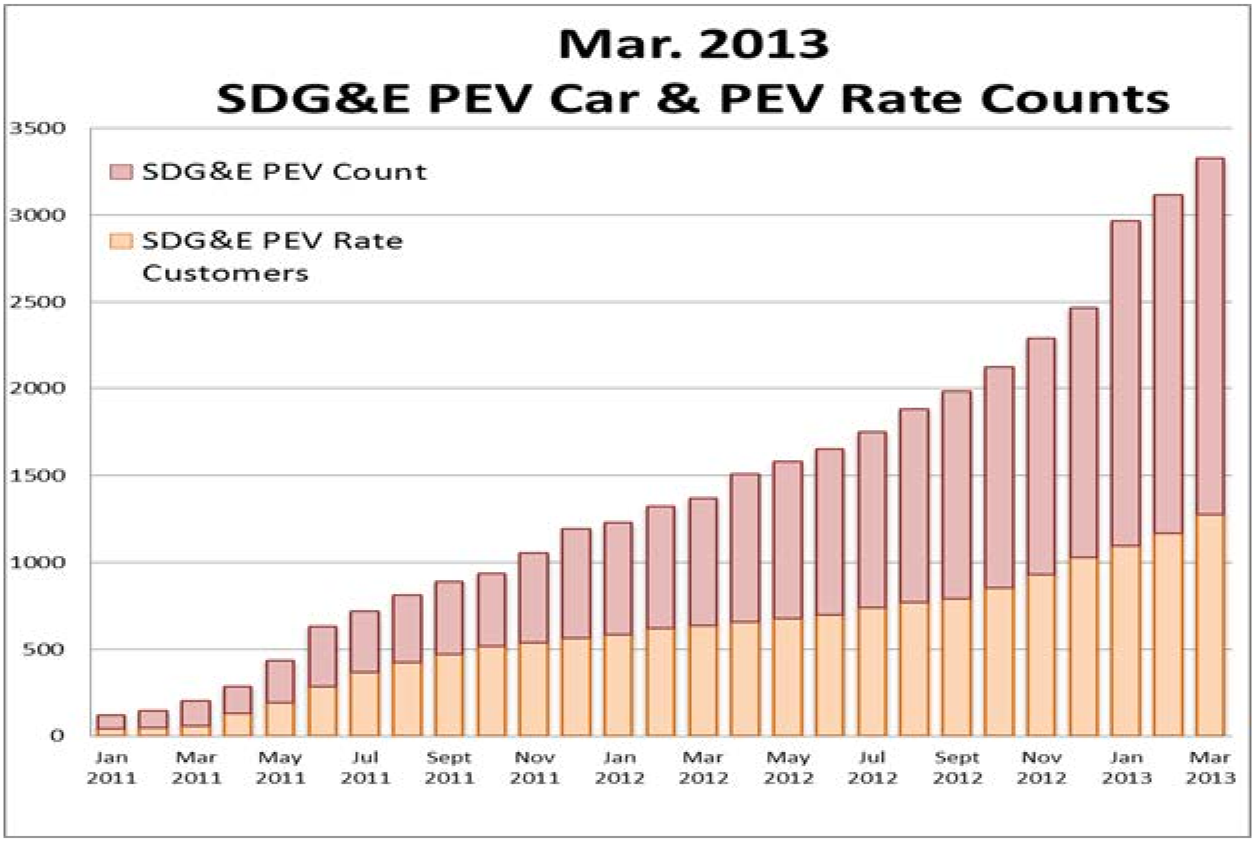

Figure 10 – Histogram of SDG&E PEV customer growth and rate category

The test bed circuit will be developed based on the common characteristics as identified and reported for the top ranked circuit(s). To capture the effect of actual charging patterns, the test system will incorporate scaling up the simulated PEV charging according to a target number of PEV customers per service transformer and at various locations. The extracted PEV charging patterns will be utilized to determine both circuit level impacts and individual component level impacts.

5. References

[1]. Von Altrock, Constantin (1995). Fuzzy logic and NeuroFuzzy applications explained. Upper Saddle River, NJ: Prentice Hall PTR.

[2]. The MathWorks – Accelerating the pace of Engineering and Science Website, Fuzzy Interface Process R2012b - http://www.mathworks.com/help/fuzzy/fuzzy-inference-process.html.

[3]. L. Xu, M. Marshall, L. Dow, "A Framework for Assessing the Impact of Plug-in Electric Vehicle to Distribution Systems", in Proceedings of 2011 IEEE PSCE, Mar 2011, Phoenix, AZ.

[4]. Folland, G.B. (1999). Real Analysis: Modern Techniques and Their Applications (Second ed.). John Wiley & Sons, Inc.

Appendix A – Detailed Fuzzy Logic Methodology and Example

This section describes the fuzzy inference process. The basic fuzzy algorithm structure applied in this study is shown in the following diagram. Information flows from left to right, from five circuit attributes (only three shown in the figure) to a single output (i.e., the score for each circuit).

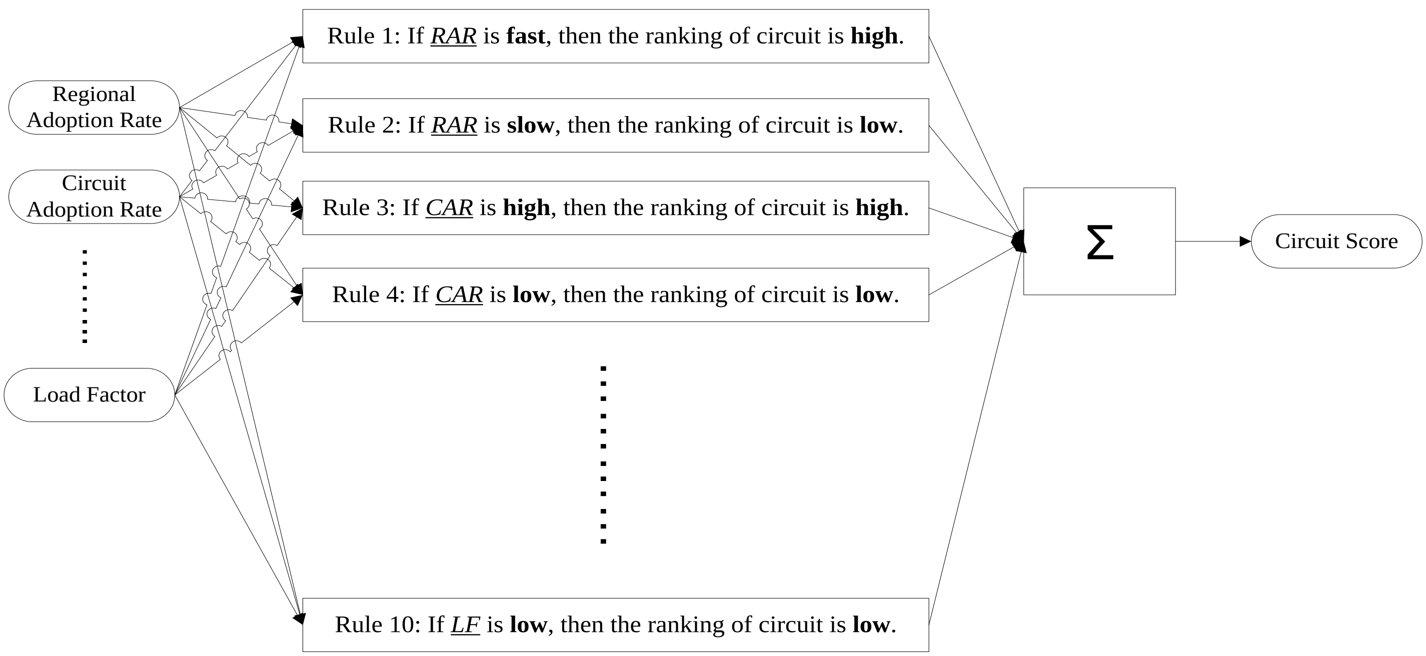

Figure 11 – Fuzzy Inference Diagram

Input Normalization

As indicated earlier, the input data are first normalized to the range of [0, 1] to avoid any potential bias due to different magnitudes of input variables. During the normalization process, the smallest value of an attribute is set to 0, the largest value of the attribute is set to 1, and all the remaining values are linearly normalized to a value between 0 and 1. For instance, Table 6 in Appendix B lists the raw data for circuit length. The shortest circuit length is 19,953 ft (Circuit A); its normalized value is 0, as shown in Table 3. The longest circuit length is 54,086 ft (Circuit I); its normalized value is 1. The normalized values of circuit length, along with those of other selected attributes, are input to the fuzzy algorithm. The complete input normalization data are presented in Table 4.

Table 3 – Normalization of Circuit Length

Circuit ID	Circuit Length (ft)	Normalized Input
A	19,953	0.00
B	46,848	0.79
C	30,203	0.30
D	37,472	0.51
E	42,646	0.66
F	27,682	0.23
G	41,352	0.63
H	34,032	0.41
I	54,086	1.00
J	36,690	0.49
K	27,458	0.22

Fuzzy Rules

Basic if-then rules are adopted in this study to define the mapping from circuit features to its likelihood of being impacted by high penetration of PEV charging. The if-then rules utilized in the algorithms are listed below:

- If *PEV regional adoption rate* is **fast**, then the ranking of circuit being both representative and prone to high PEV penetration is **high**.
- If *PEV regional adoption rate* is **slow**, then the ranking of circuit being both representative and prone to high PEV penetration is **low**.
- If *PEV circuit adoption rate* is **high**, then the ranking of circuit being both representative and prone to high PEV penetration is **high**.
- If *PEV circuit adoption rate* is **low**, then the ranking of circuit being both representative and prone to high PEV penetration is **low**.
- If *PEV adoption diversity factor* is **large**, then the ranking of circuit being both representative and prone to high PEV penetration is **high**.
- If *PEV adoption diversity factor* is **small**, then the ranking of circuit being both representative and prone to high PEV penetration is **low**.
- If *Circuit length* is **long**, then the ranking of circuit being both representative and prone to high PEV penetration is **high**.
- If *Circuit length* is **short**, then the ranking of circuit being both representative and prone to high PEV penetration is **low**.

- If *PEV load factor* is **high**, then the ranking of circuit being both representative and prone to high PEV penetration is **high**.
- If *PEV load factor* is **low**, then the ranking of circuit being both representative and prone to high PEV penetration is **low**.

This study is built on ten rules and each of the rules depends on resolving the inputs into a fuzzy linguistic set: regional adoption rate is fast, regional adoption rate is slow, circuit length is long, circuit length is short, and so on. Same for the antecedent part of the rule, the consequent part of the rule is also a fuzzy set: either the circuit score/ranking is high or the circuit score/ranking is low. It is also represented by a membership function. In this study, triangle membership function is also the form used.

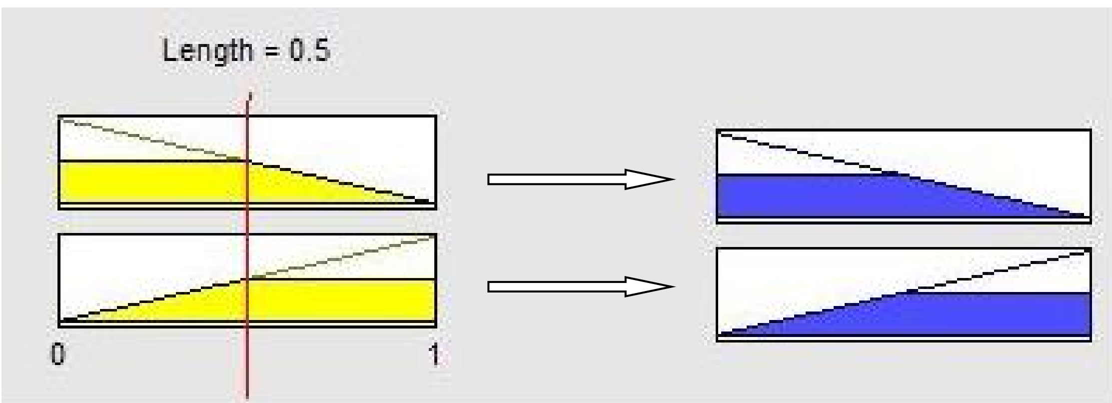

Figure 12 – Fuzzy Rules Implication

Circuit length is used as an example to explain the fuzzy rule inference or implication. In Figure 12, the left part colored in yellow represents the antecedent of the rules and the right part colored in blue represents the consequent of the rules. The top row represents the rule (*If circuit length is short, then the ranking of circuit is low*) and the bottom row represents the rule (*If circuit length is long, then the ranking of circuit is high*).

The input for the implication process is a single number given by the antecedent (0.5 in this example) and the output is a fuzzy set. The commonly used implication method is to truncate the output fuzzy set (indicated by blue color). Therefore, the consequent is reshaped using a function associated with the antecedent.

Appendix B – Summary of Raw Circuit Data for Circuit Selection and Study

The following data were used for circuit selection:

Regional Adoption Rate

Table 4 – Raw Data for PEV Regional Adoption Rate

Circuit ID	Substation Name	# PEV	Regional Adoption Rate (% of Total PEV in SDGE[1])
A	DM	63	4.94%
B	NCW	66	5.17%
C	NCW	66	5.17%
D	DM	63	4.94%
E	CC	50	3.92%
F	RN	50	3.92%
G	EN	50	3.92%
H	PO	33	2.59%
I	MRM	14	1.10%
J	CB	14	1.10%
K	EL	21	1.65%

[1]The total number of existing PEV installations as of Jan. 2013 is 1276 in SDG&E service territory.

Adoption Diversity Factor

Table 5 – Raw Data for PEV Adoption Diversity Factor

Circuit ID	Circuit PEV/Substation PEV (%)	Adoption Diversity Factor
A	22.22%	4.50
B	34.85%	2.87
C	25.76%	3.88
D	19.05%	5.25
E	22.00%	4.55
F	22.00%	4.55
G	22.00%	4.55
H	45.45%	2.20
I	78.57%	1.27
J	78.57%	1.27
K	52.38%	1.91

Circuit Length

Table 6 – Raw Data for Circuit Length

Circuit ID	OH Length (Feet)	UG Length (Feet)	Total Circuit Length (Feet)
A	14,619	5,334	19,953
B	0	46,848	46,848
C	0	30,203	30,203
D	13,534	23,938	37,472
E	2,140	40,506	42,646
F	4,734	22,948	27,682
G	27,314	14,038	41,352
H	24,114	9,918	34,032
I	0	54,086	54,086
J	27,923	8,767	36,690
K	0	27,458	27,458

Circuit Adoption Rate

Table 7 – Raw Data for PEV Circuit Adoption Rate

Circuit ID	# Residential Customer	Circuit Adoption Rate (PEV/Residential Customer)
A	1,728	0.81%
B	2,199	1.05%
C	2,291	0.74%
D	3,444	0.35%
E	2,730	0.40%
F	2,606	0.42%
G	4,672	0.24%
H	2,020	0.74%
I	3,159	0.35%
J	3,626	0.30%
K	3,337	0.33%

Load Factor

Table 8 – Raw Data for PEV Load Factor

Circuit ID	Historical Load (Amps)	Load Factor PEV/Load (%)
A	189.00	7.41%
B	527.16	4.36%
C	404.08	4.21%
D	474.48	2.53%
E	406.68	2.70%
F	222.12	4.95%
G	473.80	2.32%
H	468.00	3.21%
I	375.60	2.93%
J	385.48	2.85%
K	445.00	2.47%

Appendix C – Detailed PEV Charging Patterns

EPEVH

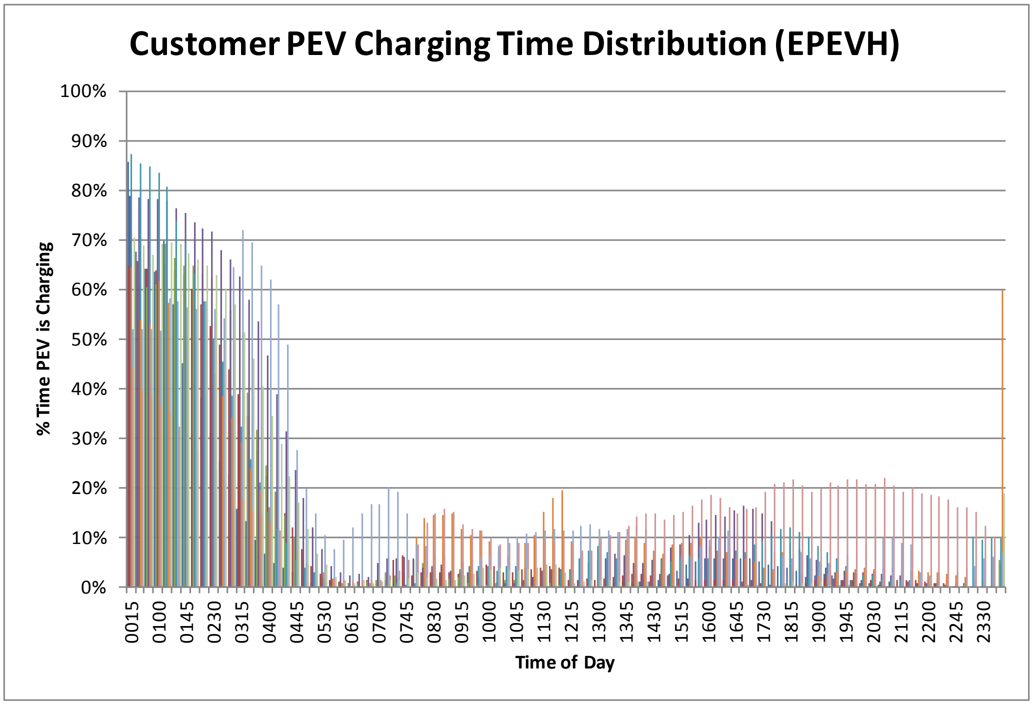

Figure 13 – PEV Charging Time Distribution (9 EPEVH Customers)

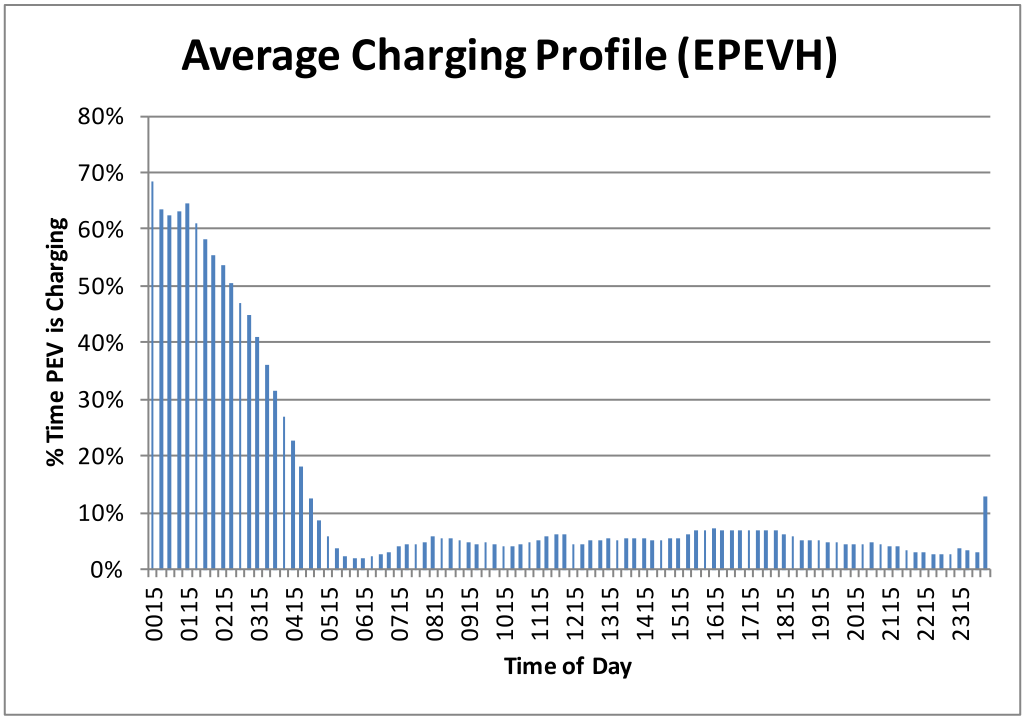

Figure 14 – Average PEV Charging Time Distribution (9 EPEVH Customers)

EPEVM

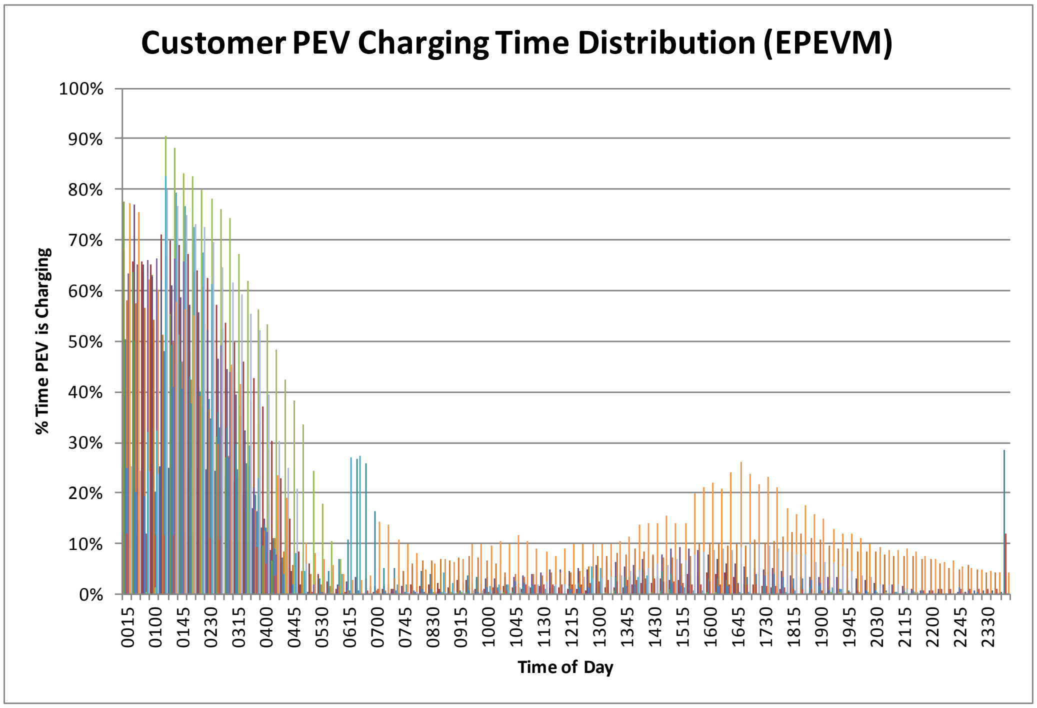

Figure 15 – PEV Charging Time Distribution (13 EPEVM Customers)

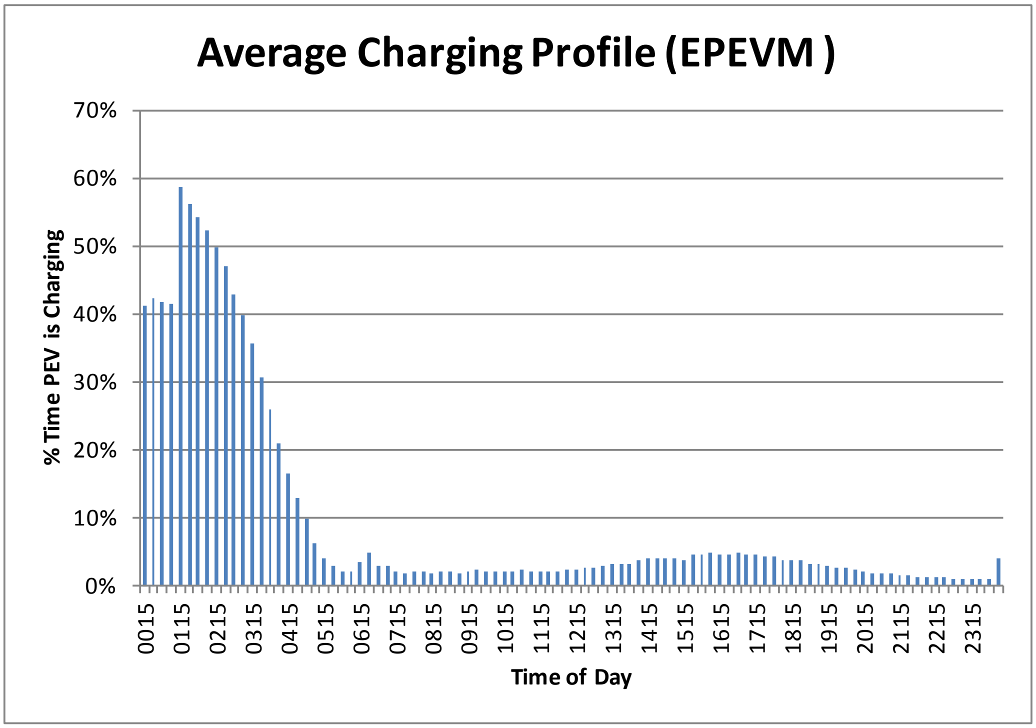

Figure 16 – Average PEV Charging Time Distribution (13 EPEVM Customers)

EPEVL

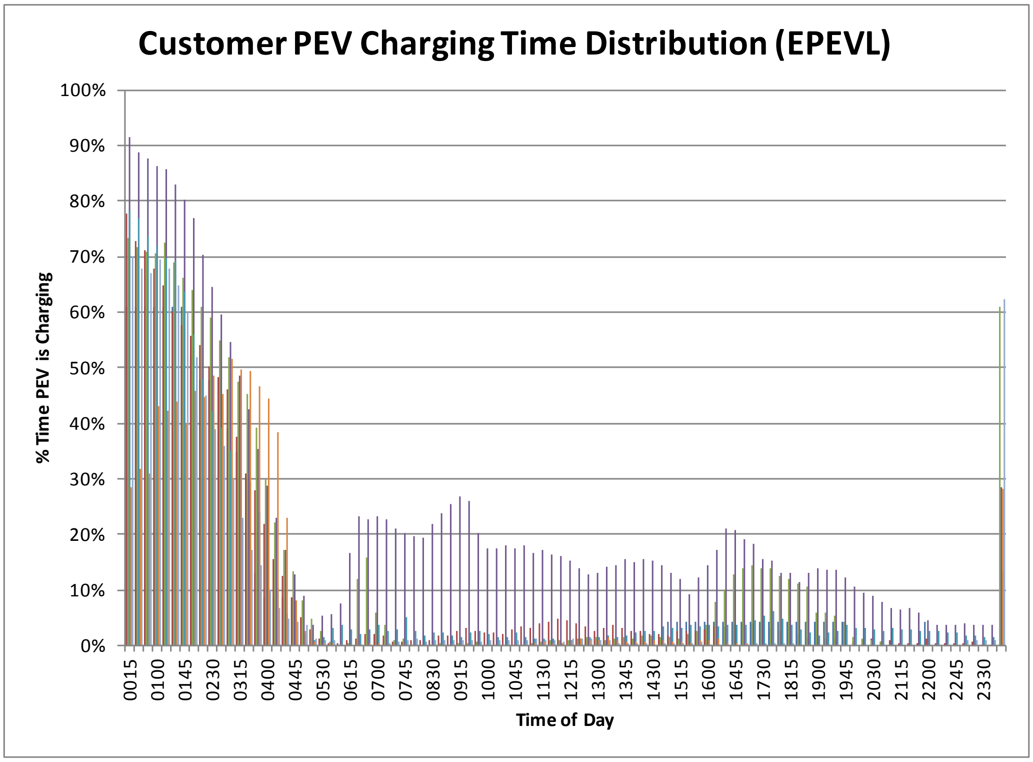

Figure 17 – PEV Charging Time Distribution (7 EPEVL Customers)

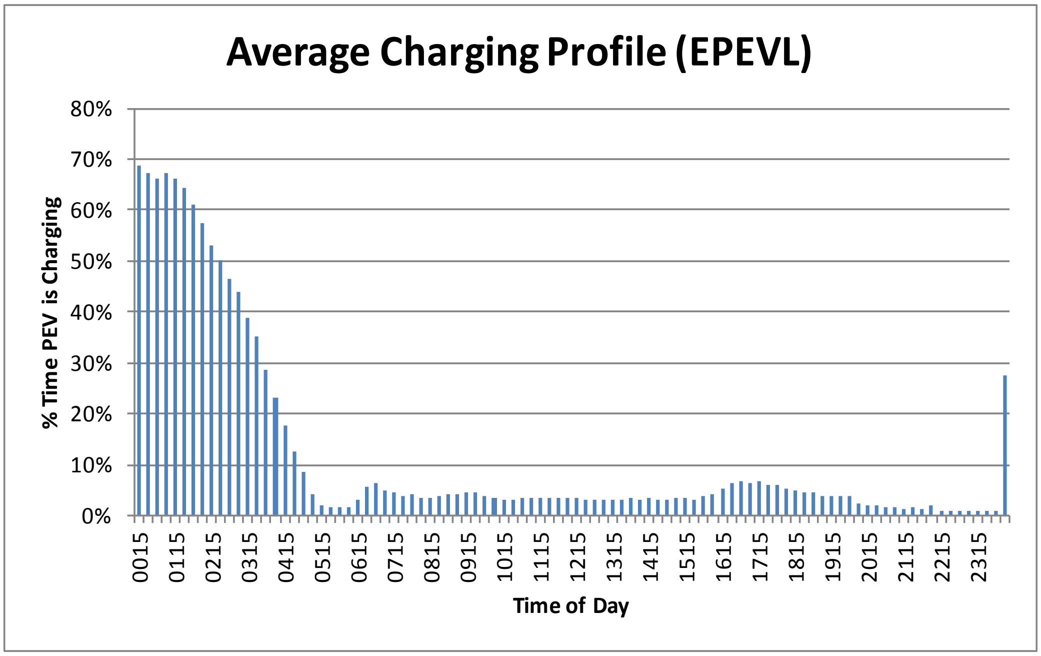

Figure 18 – Average PEV Charging Time Distribution (7 EPEVL Customers)

Charging Time Pattern

Table 9 – Numeric Typical PEV Charging Time Pattern

Time	% of Time PEV is Charging	Time	% of Time PEV is Charging	Time	% of Time PEV is Charging
0015	56.2%	**0815**	3.3%	**1615**	5.5%
0030	55.0%	**0830**	3.6%	**1630**	5.8%
0045	54.0%	**0845**	3.7%	**1645**	5.9%
0100	54.4%	**0900**	3.5%	**1700**	5.8%
0115	62.4%	**0915**	3.5%	**1715**	5.7%
0130	59.7%	**0930**	3.6%	**1730**	5.6%
0145	57.1%	**0945**	3.4%	**1745**	5.5%
0200	54.5%	**1000**	3.2%	**1800**	5.2%
0215	51.8%	**1015**	3.0%	**1815**	4.8%
0230	48.8%	**1030**	3.0%	**1830**	4.6%
0245	45.0%	**1045**	3.2%	**1845**	4.2%
0300	42.3%	**1100**	3.3%	**1900**	4.0%
0315	38.0%	**1115**	3.3%	**1915**	3.8%
0330	33.5%	**1130**	3.6%	**1930**	3.6%
0345	28.3%	**1145**	3.7%	**1945**	3.5%
0400	23.3%	**1200**	3.8%	**2000**	3.0%
0415	18.7%	**1215**	3.2%	**2015**	2.9%
0430	14.4%	**1230**	3.4%	**2030**	2.8%
0445	10.3%	**1245**	3.6%	**2045**	2.6%
0500	6.6%	**1300**	3.7%	**2100**	2.5%
0515	4.1%	**1315**	3.8%	**2115**	2.4%
0530	2.9%	**1330**	3.9%	**2130**	2.3%
0545	2.1%	**1345**	4.0%	**2145**	1.9%
0600	2.0%	**1400**	4.2%	**2200**	2.0%
0615	3.0%	**1415**	4.3%	**2215**	1.8%
0630	4.3%	**1430**	4.2%	**2230**	1.7%
0645	3.6%	**1445**	4.2%	**2245**	1.5%
0700	3.5%	**1500**	4.4%	**2300**	1.6%
0715	3.2%	**1515**	4.3%	**2315**	1.8%
0730	3.2%	**1530**	4.7%	**2330**	1.7%
0745	3.3%	**1545**	5.2%	**2345**	1.6%
0800	3.3%	**1600**	5.4%	**2400**	12.5%

Charging Demand Pattern

Table 10 – Numeric Typical PEV Charging Demand Pattern

Time	Charging Demand (kW)	Time	Charging Demand (kW)	Time	Charging Demand (kW)
0015	3.15	**0815**	2.88	**1615**	2.94
0030	3.62	**0830**	2.97	**1630**	3.06
0045	3.68	**0845**	2.77	**1645**	3.18
0100	3.49	**0900**	3.07	**1700**	3.30
0115	3.54	**0915**	3.05	**1715**	3.11
0130	3.60	**0930**	3.08	**1730**	3.14
0145	3.60	**0945**	3.17	**1745**	3.06
0200	3.56	**1000**	3.11	**1800**	3.13
0215	3.56	**1015**	3.12	**1815**	3.03
0230	3.52	**1030**	3.22	**1830**	2.88
0245	3.50	**1045**	3.05	**1845**	3.12
0300	3.37	**1100**	3.28	**1900**	2.89
0315	3.32	**1115**	3.12	**1915**	3.01
0330	3.24	**1130**	3.10	**1930**	2.85
0345	3.12	**1145**	3.09	**1945**	3.20
0400	3.06	**1200**	2.90	**2000**	3.14
0415	3.00	**1215**	3.14	**2015**	3.13
0430	2.85	**1230**	3.11	**2030**	3.17
0445	2.56	**1245**	3.08	**2045**	3.27
0500	2.43	**1300**	3.03	**2100**	3.29
0515	2.15	**1315**	3.11	**2115**	3.24
0530	2.00	**1330**	3.08	**2130**	3.40
0545	2.12	**1345**	3.18	**2145**	3.67
0600	2.05	**1400**	3.09	**2200**	1.87
0615	2.15	**1415**	3.05	**2215**	2.94
0630	2.20	**1430**	3.27	**2230**	3.06
0645	2.30	**1445**	3.19	**2245**	3.18
0700	2.42	**1500**	3.09	**2300**	3.30
0715	2.45	**1515**	3.29	**2315**	3.11
0730	2.67	**1530**	3.22	**2330**	3.14
0745	2.59	**1545**	3.27	**2345**	3.06
0800	2.57	**1600**	3.29	**2400**	3.13